INTERIM
IN-48
234599

Semi-Annual Progress Report

July 1998

Mark R. Abbott

College of Oceanic and Atmospheric Sciences

Oregon State University

MODIS Team Member, Contract # NAS5-31360

Task Objectives

The objectives of the last six months were:

- Continue analysis of Hawaii Ocean Time-series (HOT) bio-optical mooring data,
- Recover instrumentation from JGOFS cruises in the Southern Ocean and analyze data
- Maintain documentation of MOCEAN algorithms and software for use by MOCEAN and GLI teams
- Continue chemostat experiments on the relationship of fluorescence quantum yield to environmental factors.
- Continue to develop and expand browser-based information system for in situ bio-optical data

Work Accomplished

Analysis of Field Data from Hawaii

We are continuing to analyze bio-optical data collected at the Hawaii Ocean Time Series mooring. The HOT bio-optical mooring was recovered in May 1998. After retrieving the data, the sensor package was serviced and redeployed. We now have over 18 months of data. These are being analyzed as part of a larger study of mesoscale processes at this JGOFS time series site. We have had some failures in the data logger which have affected the fluorescence channels. These are being repaired. We also had an instrument housing failure, and minor modifications have been made to avoid subsequent problems.

In addition, Ricardo Letelier is funded as part of the SeaWiFS calibration/validation effort (through a subcontract from the University of Hawaii, Dr. John Porter), and he is collecting bio-optical and fluorescence data as part of the HOT activity. This will provide additional in situ measurements for MODIS validation. These data may be obtained at our Web site, http://picasso.oce.orst.edu/users/jasmine/ORSOO . The data have also been provided to the SIMBIOS project.

Analysis of Data from the Southern Ocean

At the 1998 Ocean Sciences meeting, we presented a paper on results from three Southern Ocean drifters, focusing on the diel variations in fluorescence quantum yield. Figure 1 below shows apparent quantum yield of fluorescence during two five-day periods for one of the drifters based on the slopes of the relationship between fluorescence/chlorophyll and solar irradiance. Note the dramatic decrease in slope, indicating that phytoplankton were growing more rapidly in this second period. Figure 2 is the time series of the apparent quantum yield from the same drifter. The oscillations early in the record are associated with meanders of the Polar Front. These meanders result in colder, higher chlorophyll and higher productivity (based on fluorescence quantum yield) on the northward portion of the meanders where the flow is divergent. The opposite characteristics prevail in the southward, convergent portion of the meander. The large-scale decline in quantum yield was apparently associated with a large-scale shift in phytoplankton community structure that perhaps was indicative of the spring bloom. A drifter 200 km away recorded the same shift in quantum yield.

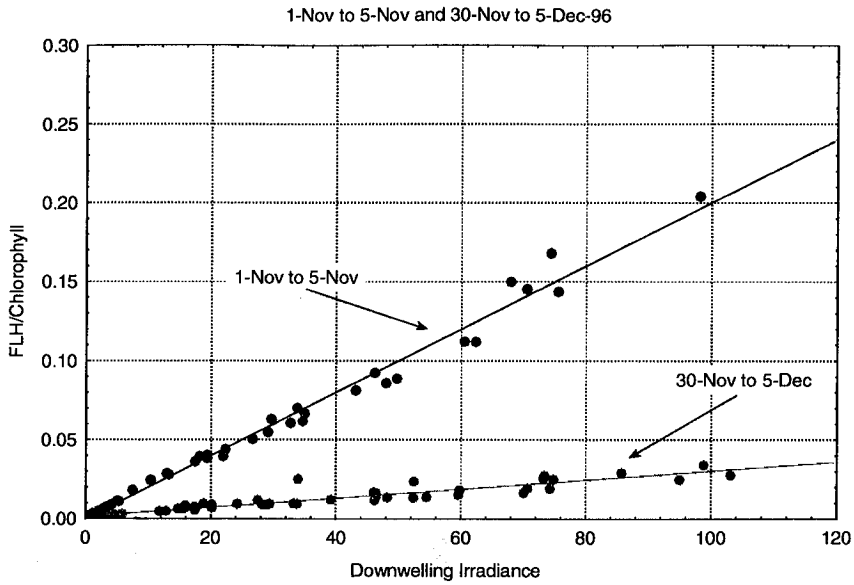


Figure 1. Relationship between fluorescence/chlorophyll and solar irradiance for two five-day periods as measured from a bio-optical drifter in the Southern Ocean in 1996.

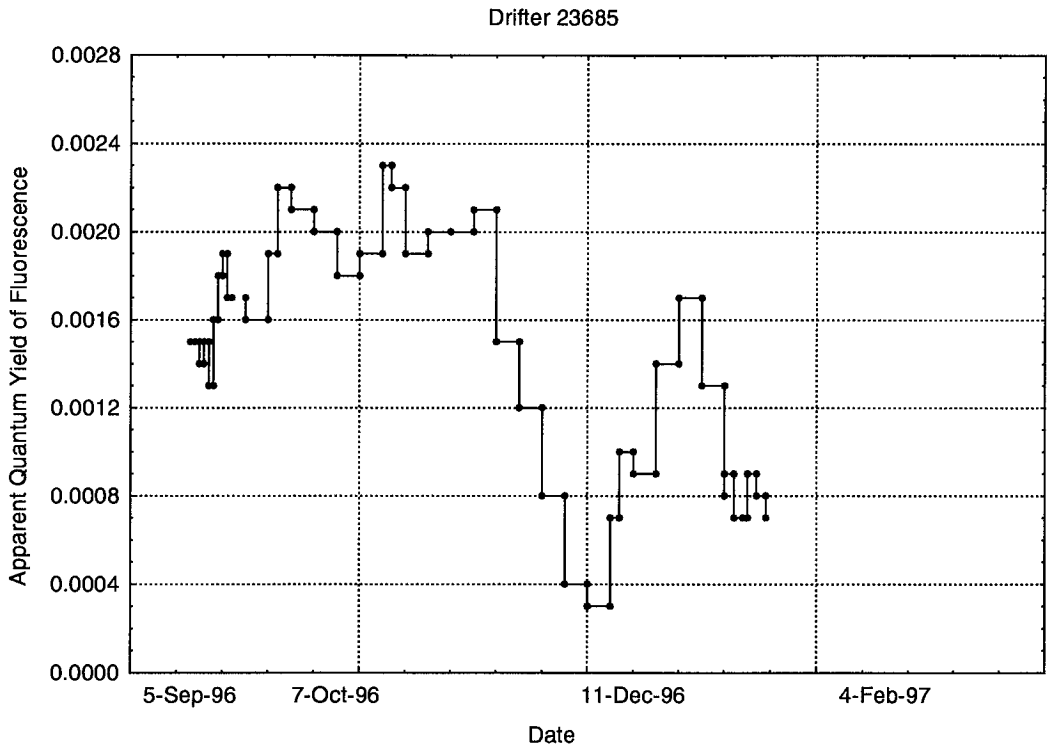


Figure 2. Apparent quantum yield of fluorescence from a bio-optical drifter in the Southern Ocean in 1996

From October-November 1997, we participated in the first survey cruise of the Antarctic Polar Front as part of JGOFS. We deployed 12 moorings, each equipped with a current meter and an irradiance sensor. Six of the moorings also had a conductivity/temperature sensor. These moorings were deployed in a grid with spacing of approximately 30 km between each mooring (Figure 3). We also deployed 10 bio-optical drifters and 10 conventional drifters. Unfortunately, two of the bio-optical drifters failed on deployment, but the vendor provided us with free replacements. Figure 4 shows the positions of the moorings and the drifter tracks from the first few days of the deployments. This information is overlain on a map of SST derived from SeaSoar measurements. Note the strong meandering of the flow field, which is associated

with upwelling and downwelling. Initially, the drifters pass through a downwelling region which is associated with strong convergence of the drifter tracks. This is followed by upwelling in a divergence region in the meander. This area of upwelling had high chlorophyll levels. The iceberg shown in Figure 3 damaged one of our moorings which was subsequently lost.

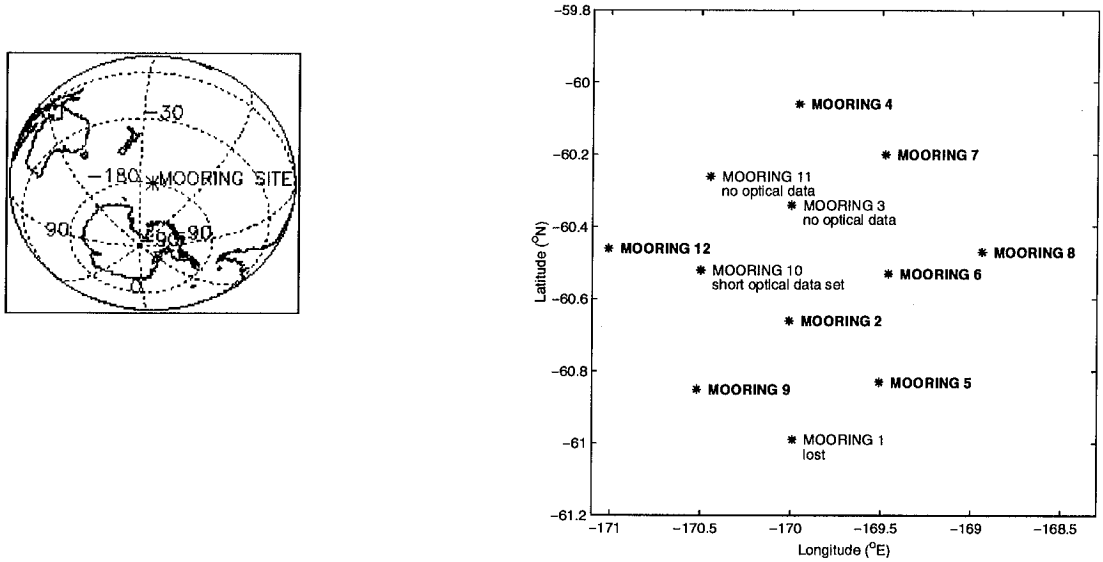


Figure 3. Map of mooring locations in the APFZ.

Figure 5 shows a time series of E_d555/E_d443 as a surrogate for chlorophyll. Note the strong spring bloom present in all of the moorings. This bloom was detected in SeaWiFS imagery as well. Figure 6 is the monthly composite for December 1997 and shows the high chlorophyll levels associated with the bloom at the Polar Front. Figure 7 shows the SeaWiFS chlorophyll measurements at the mooring locations for the same time period.

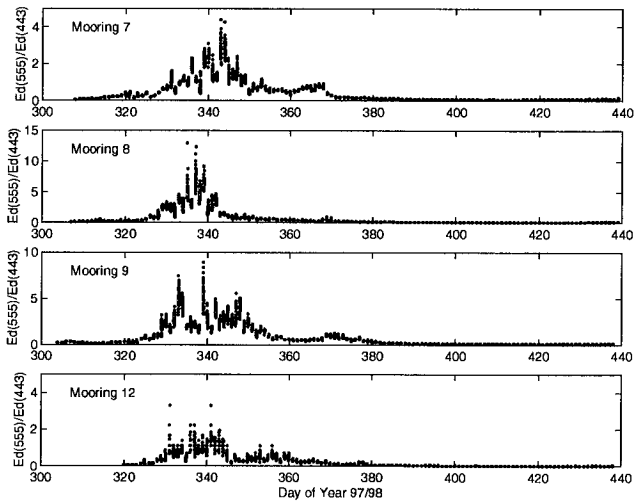
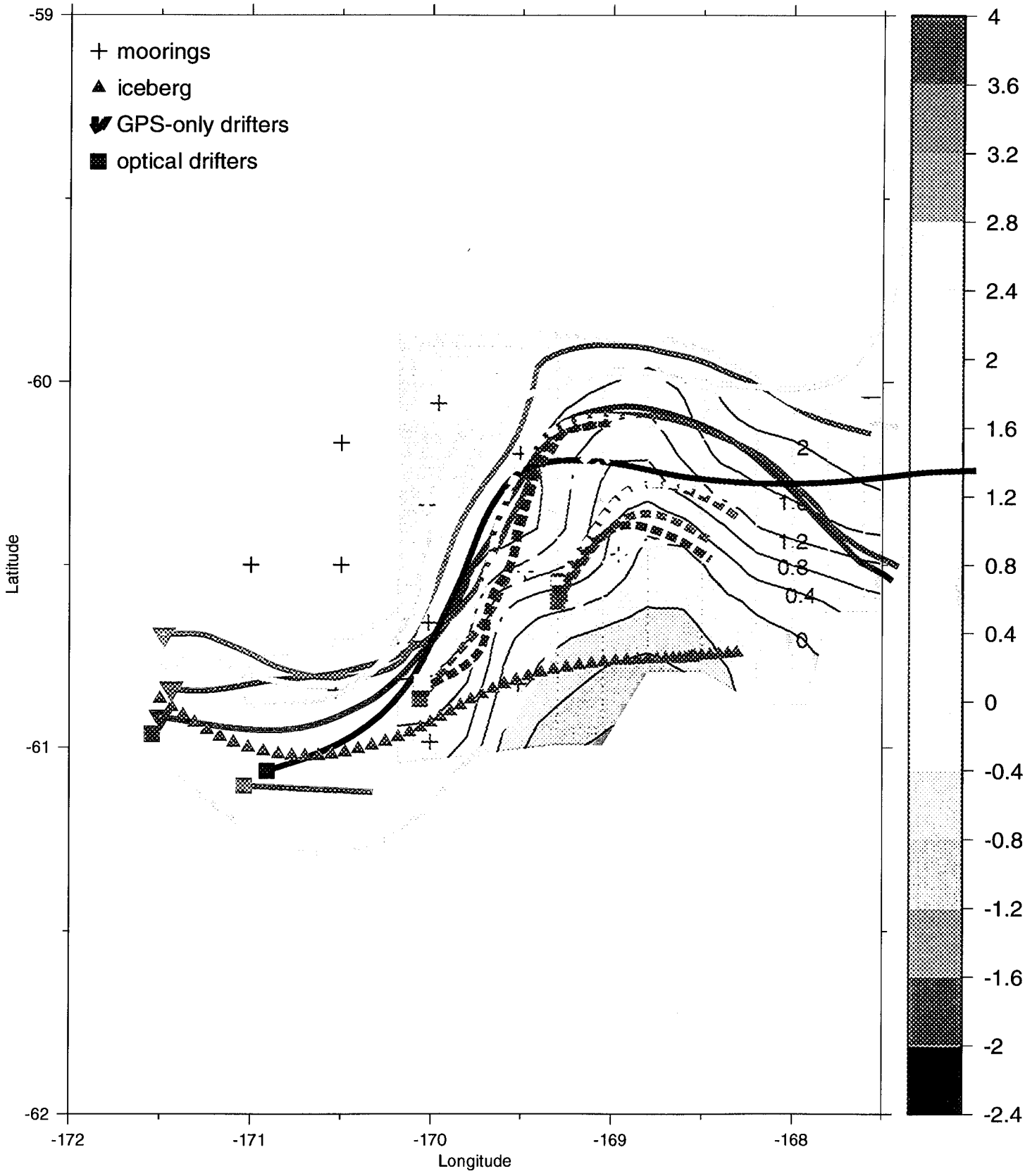


Figure 5. Time series of E_d555/E_d443 as a surrogate for chlorophyll from 4 of the bio-optical moorings. Note the presence of a spring bloom in all of the records.

Sea Surface Temperature (°C) SOJGOFS Survey 1, 15-19 Nov 1997

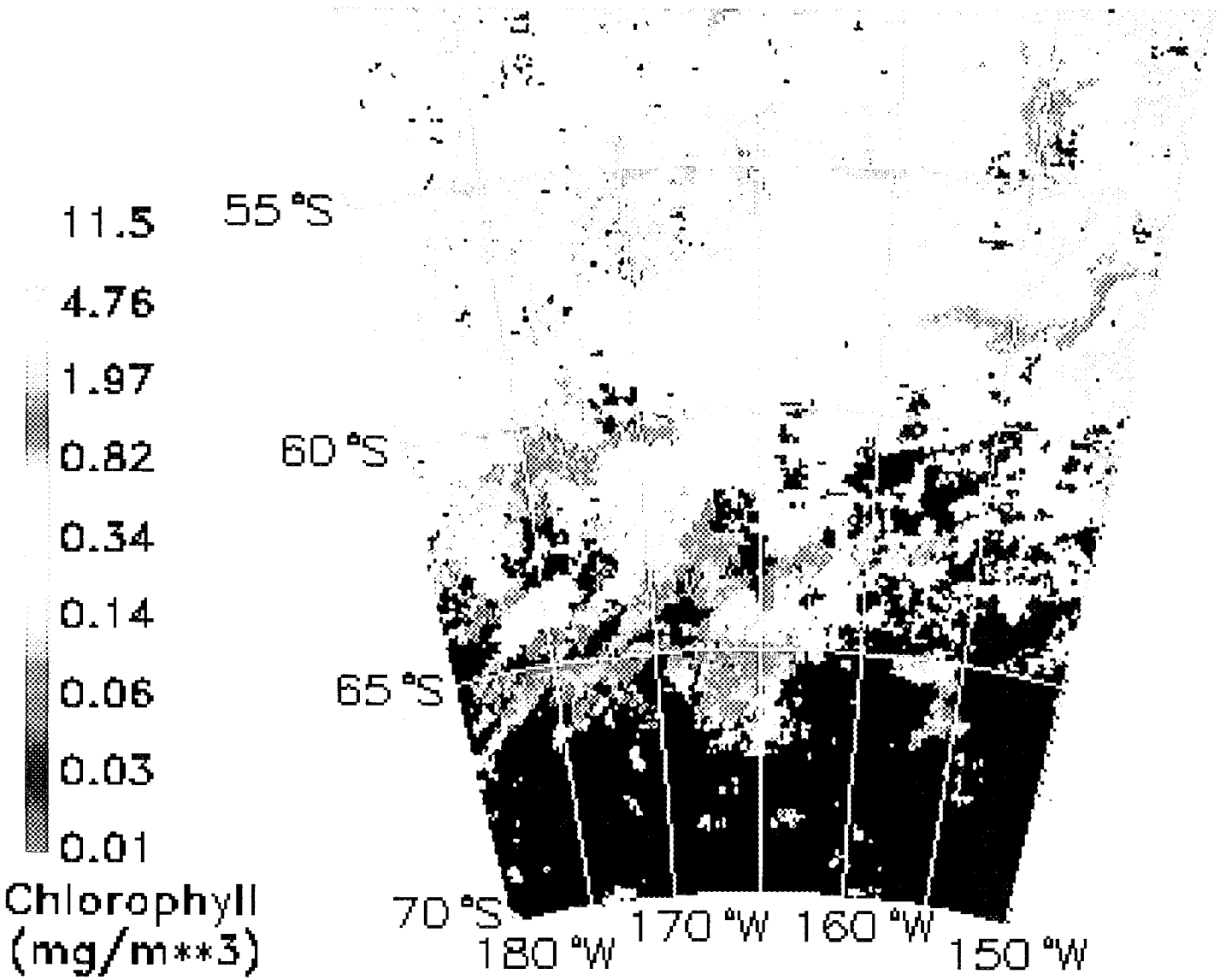
Drifters from 8-20 November 1997



Preliminary

Oregon State University SeaSoar Group

Oregon State University Mooring Group



Process I (12/3 – 1/3)

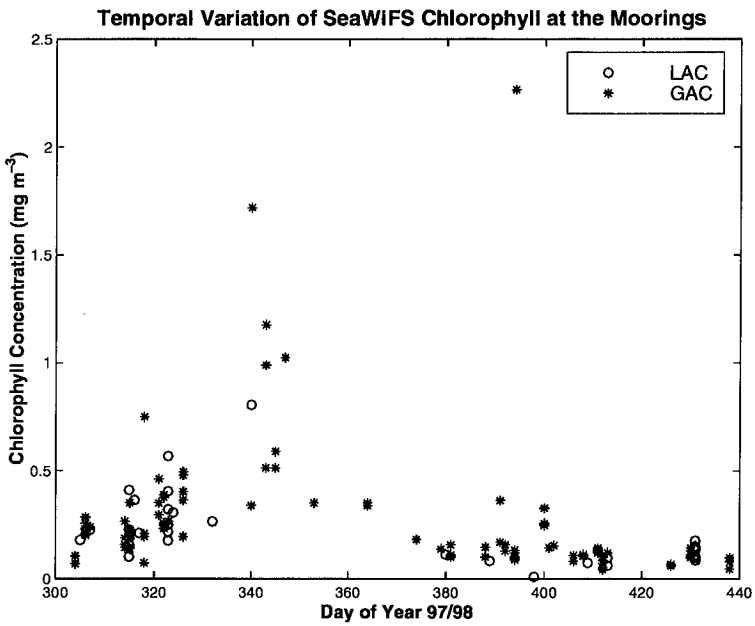


Figure 7. Chlorophyll at the mooring locations as measured by SeaWiFS. For comparison, see Figure 5.

We deployed three clusters of drifters to study the convergence/divergence field associated with the PF. Two clusters were deployed in the first survey and a third cluster was deployed in the second APFZ survey. Two bio-optical drifters were deployed during the final APFZ process cruise. Most of the drifters survived several months as projected and traveled to the Mid-Pacific Rise where they were trapped in the rough topography of the Eltanin Fracture Zone. They eventually failed after 6 months. There was strong meandering of the PF as expected and bottom topography on strongly affects the circulation of the Antarctic Circumpolar Current. The most recent set of drifter tracks is shown in Figure 8. Note that the main cluster of drifters follows the PF, showing strong divergence near 160°W, associated with the Pacific Antarctic Rise. We expect that primary productivity will be stimulated by the upwelling forced by this divergence. Note also that several drifters are "kicked" out of the PF to the north. This may be an important mechanism for meridional exchange of heat and nutrients.

The Tethered Spectral Radiometer Buoy II was deployed at several stations during the cruise. Chlorophyll values were generally low, given the deep mixing present in the PF during early spring. The TSRB II values agreed quite well with chlorophyll extractions made from near-surface water samples. Sun-stimulated fluorescence was also measured, and these data are now being analyzed.

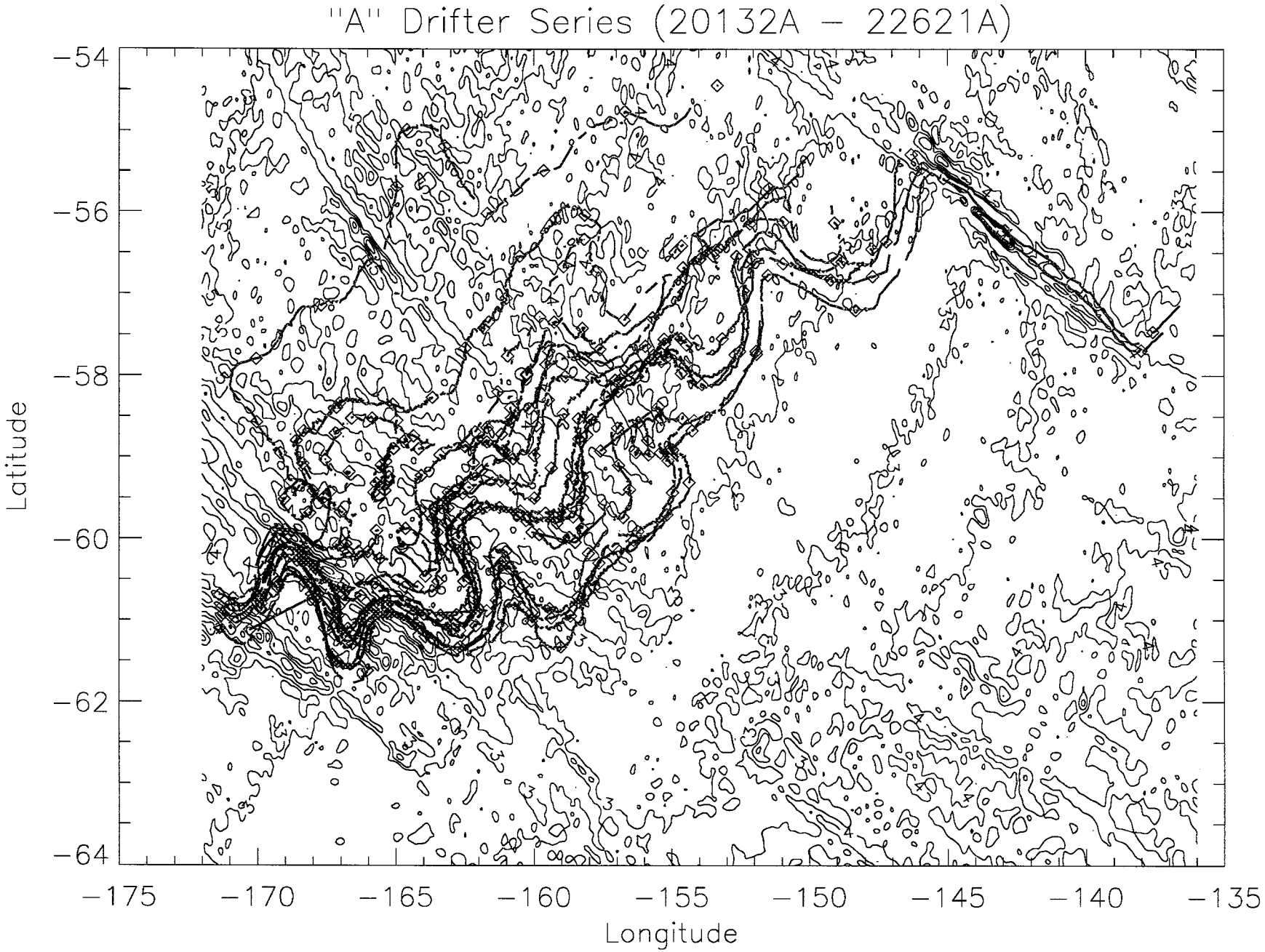
The Fast Repetition Rate (FRR) fluorometer was deployed during the second JGOFS survey to the Polar Front. Although the data were reasonable, there were several technical problems with the operation of the FRR fluorometer. Most notably, the underwater connectors and some elements of the software were poorly designed, resulting in some data loss The fluorometer will be shipped back to Chelsea Instruments in the United Kingdom and will be replaced with an upgraded model. However, the data that were recovered look intriguing. To support analysis of the FRR data, over 400 samples were collected for detailed pigment analysis using HPLC.

MOCEAN Algorithm Documentation

As part of our joint MODIS/GLI activities, we have developed a complete set of on-line documentation for the MODIS Ocean algorithms. This Web page can be accessed at http://picasso.oce.orst.edu/users/jasmine/MODP/. We have maintained this page in cooperation with the University of Miami. We have distributed the Version 2 MODIS Ocean codes to the GLI team and to Dr. Jim Yoder, Univ. Rhode Island.

Chemostat Experiments

For this report, our focus will be on chemostat experiments with sun-stimulated fluorescence. During


"A" Drifter Series (20132A – 22621A)
Latitude
−54
−56
−58
−60
−62
−64
−175
−170
−165
−160
−155
−150
−145
−140
−135
Longitude

photosynthesis, the sun-stimulated (also called passive or natural) fluorescence is a passive signal emitted by the photosystem that can be affected by changes in temperature, nutrient and light availability. Because variations in the amount of fluorescence emitted per unit light absorbed (fluorescence quantum yield) take place in response to changes in the energy distribution in the photosystem, we can expect these variations to be the first direct signal of biological response to physical and chemical changes.

To date our ability to study in situ biological/physical coupling at small scales has been limited by our capacity to monitor biological parameters that respond to environmental perturbations in time scales smaller than 1 day. Furthermore, many of the present techniques to monitor phytoplankton biomass are based on the measurement of chlorophyll fluorescence and assume a constant emission of light per unit chlorophyll.

Using a chemostat that allows the continuous monitoring of passive fluorescence and fluorescence quantum yield under nutrient, light and temperature controlled conditions, we propose to quantify the time scales of the physiological response of phytoplankton (as manifested in the chlorophyll fluorescence) to environmental variability. This information is crucial for the development of models of coupled ocean physics and biology as well as for the design and analysis of next-generation in situ instrumentation which rely on passive sensing of phytoplankton.

In pelagic ecosystems, the temporal scale of phytoplankton response to changes in the physical and chemical forcing (temperature, light and nutrient availability) is predictable and ranges from short-term (seconds), with rapid physiological adaptations, to long-term (years), with gradual community and evolutionary changes. However, most of our historical understanding and characterization of physical-biological interactions in pelagic systems stems from field studies appropriate for meso- and long- scale (days to years) variability analyses The study of smaller scales of variability (< day) is limited by the frequency and extent sampling used to detect natural changes, and by the ability we have to monitor biological changes that occur at certain frequencies and not others.

When a change in a biological parameter being monitored is detected, it indicates that the physiological state of the biological unit studied has been removed from its optimum (equilibrium) state. In other words, physiological parameters that are slow to adapt to a transient change will reflect the perturbation only if the temporal scale of the perturbation is greater than the scale of adaptation. Perturbations of higher frequency will be filtered and the particular physiological process will remain close to its optimum value. Hence, even if a biological system is being perturbed at a given frequency, we may not be able to detect this perturbation if the signal we are monitoring corresponds to a physiological process that responds to lower frequencies.

By monitoring some specific changes in the characteristics of the photoautotrophic community it is possible to estimate different temporal scales of changes resulting from fluctuations in environmental variables. For example, while changes in pigment composition may help to identify long-term alterations in the community structure, variations in pigment concentration may indicate transient changes in photoadaptation or in the carrying capacity of the ecosystem. Furthermore, sun-stimulated chlorophyll fluorescence and the fluorescence quantum yield (the fraction of energy absorbed by the photosystem and re-emitted as red light, Φ_f) may prove to be useful as indicators of physical-biological interactions at scales smaller than 1 day or 1 km.

With the advent of automated optical, physical, and chemical sampling devices deployed in moorings, and drifters, high temporal resolution in the characterization of physical and chemical variability in pelagic ecosystems can be accomplished. However, because the detection of a biological response to an environmental perturbation is dependent on the temporal scale of the biological adaptation, the resolution scale of physical-biological interactions is limited by the kinetics of the biological process being observed.

Furthermore, autonomous sampling systems designed to monitor biological parameters rely on proxy measurements. The conversion of these proxy measurements into the quantity of interest are often affected by physiology. For example, chlorophyll concentrations are usually derived from fluorescence and absorbance measured at 683 and 490 nm, respectively. However, the amount of light emitted and absorbed per unit in vivo chlorophyll can vary significantly over small spatial and temporal scales.

The quantum yield of fluorescence varies by an order of magnitude, depending on the energy distribution within the photosystem. Because changes in the energy distribution take place at the physiological level in response to variations in temperature and nutrient and light availability, variations in $\bullet_f$ may be expected to be the first direct signal of a biological response to fluctuations in the environment affecting phytoplankton. And, although no laboratory experiments using sun-stimulated chlorophyll fluorescence have been published, laboratory results using Pulse and Probe Fluorometry, and field work using stimulated fluorescence, Fast Repetition Rate Fluorometry, and passive fluorescence suggest that sun-stimulated chlorophyll fluorescence displays a rapid response to environmental changes with lag times of only a few hours. Understanding the causes of variability in fluorescence quantum yield and quantifying its kinetics would help to: 1) resolve small scales of physical perturbation affecting phytoplankton biology in natural assemblages and 2) better constrain the errors associated with the measurement of chlorophyll based on in vivo fluorometric methods.

In order to understand the temporal scale of response of phytoplankton fluorescence to different changes in physical and chemical forcing, and how these changes in fluorescence quantum yield correlate with other physiological parameters, laboratory experiments in which environmental variables may be controlled are required. Between June 1997 and May 1998, a natural (sun-stimulated) fluorescence chemostat/turbidostat, first conceived by Dale Kiefer at University of Southern California, was modified to allow monitoring natural chlorophyll fluorescence and other photosynthetic parameters under a nutrient, temperature, light and pH controlled environment (Fig. 9).

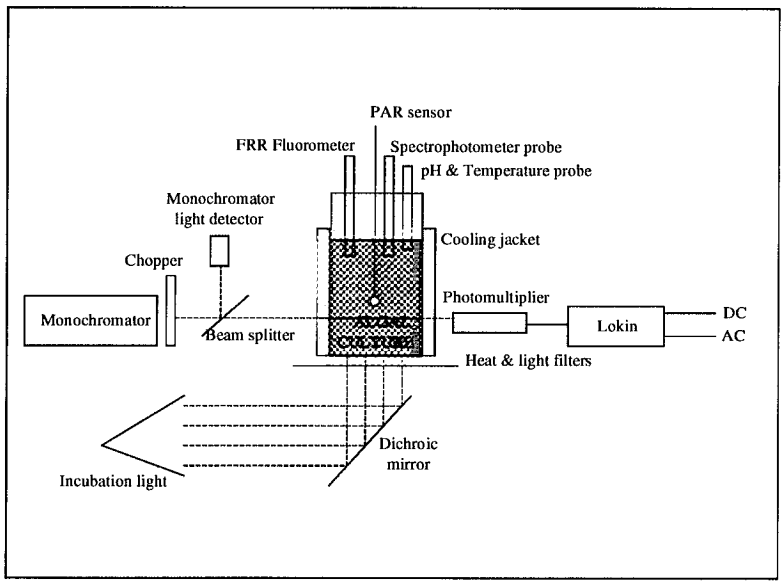


Figure 9. Diagram of the chemostat designed to study phytoplankton natural fluorescence

In its present configuration, high temporal resolution (< 1 minute) of the dynamics of natural fluorescence and fluorescence yield can be recorded in a continuous mode. Temporal variability in light, temperature, and nutrient availability are computer driven. Figure 10 displays some early results obtained with this chemostat when a culture of *Dunaliella tertiolecta* was grown under nutrient-replete and light limiting conditions. Figure 10A displays the temporal evolution of fluorescence yield (fluorescence per unit light resulting from the monochromator light pulse). Figure 10B and 10C display the temporal change in intensity of the monochromator and incubation light, respectively. Figure 10D displays the temperature in the chemostat. As expected, the fluorescence yield increases during the night and decreases during the day as a result of photoadaptation. The sharp increase and decrease at the beginning and end of the day period are probably the result of the partial closing and opening of reaction centers, respectively.

Three temporal scales of response of the photosystem are presently detected in the fluorescence trace.

While the closing and opening of reaction centers induces a shift of the fluorescence yield in the order of seconds, a slower photoadaptation process in response to the diel cycle in light takes place over a period of hours (Fig. 10A). When the maximum light intensity (solar noon) is increased (reproducing a decrease in the water-column depth at which the cells are growing) there is a significant change in the fluorescence trace between days (Fig. 11). This last scale of response is possibly the result of the combined effect of a change in size and number of photosynthetic units and an increase in the concentration of photoprotective pigments. Knowledge of the different temporal scales of response that we are able to detect monitoring changes in sun stimulated fluorescence and fluorescence quantum yield will help to design sampling and analysis strategies to pull out specific processes of interest.

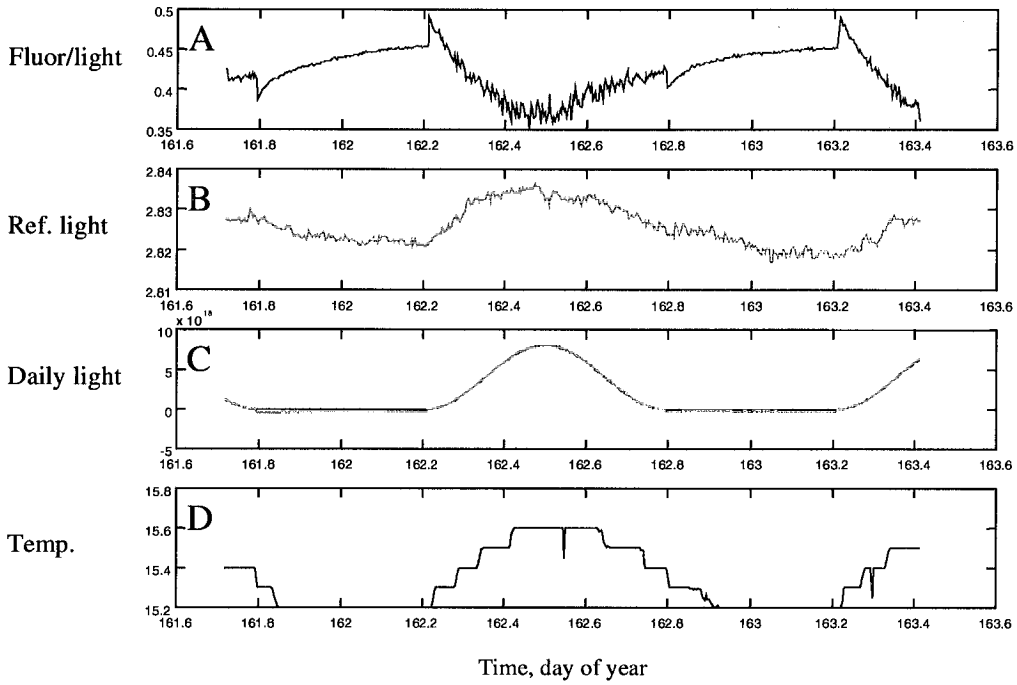


Figure 10 Temporal evolution of *Dunaliella tertiolecta* fluorescence yield grown under light limiting conditions, monochromator and incubation light intensity, and temperature in a natural fluorescence chemostat

A fast repetition rate fluorometer, to be connected to the main chemostat later this year, will facilitate the interpretation of changes in fluorescence yield and how it relates to changes in the distribution of energy in the photosystem. We will use this new facility to study how different phytoplankton taxa respond to a range of environmental fluctuations found in natural pelagic environments.

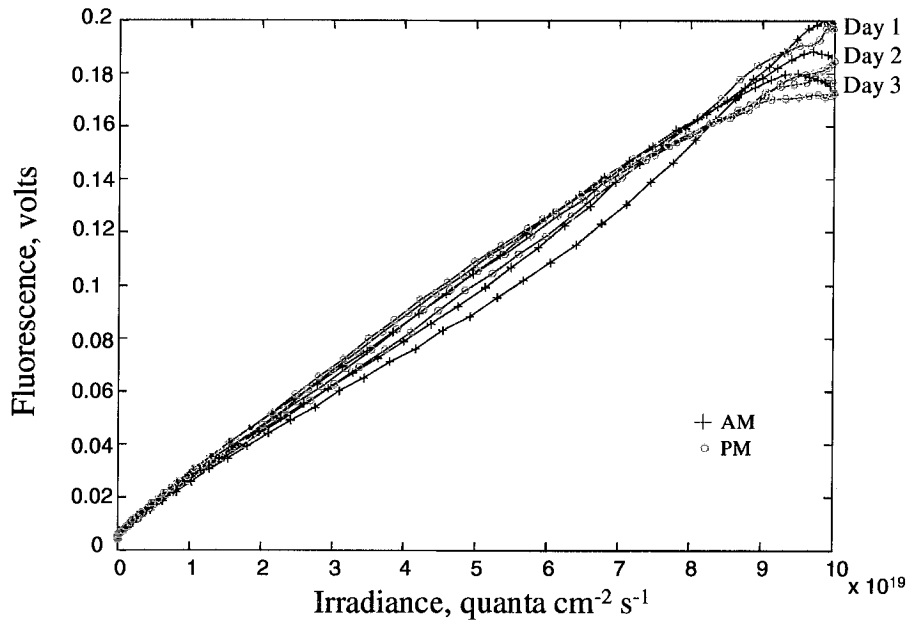


Figure 11. Evolution of natural fluorescence over the diel light cycle for three consecutive days.

The main objective during the first phase of our proposed research is to evaluate the range of scales of variability that can be studied by monitoring phytoplankton sun stimulated fluorescence. The results from these studies will help in our interpretation of the scales of variability in phytoplankton fluorescence yield observed in pelagic environments.

Two major questions to be addressed during this phase are:

1. What are the time-lag response of fluorescence to changes in nutrient (nitrogen, phosphorus, and iron), light, and temperature regimes?
2. Is there a correspondence between the magnitude of the fluorescence response and the magnitude or type of environmental change?

Experimental setup:

When addressing these two questions it will be necessary to consider: a) in what time-scales does the photosystem responds to different physical and chemical perturbations, and b) what are the perturbation minimal magnitude and duration required for the photosystem to modify its energy distribution?

To study the effect of changes in nutrient availability on the fluorescence quantum yield, we will first center our efforts in the study of nitrogen. Nitrogen pulse addition delivered to nitrogen limited cultures at various concentrations and rates will be used to study the magnitude and temporal response of the photosystem to changes in nitrogen availability.

Light perturbations will include changes in the maximum light intensity during the photoperiod as well as changes in the daily light pattern. While changes in maximum light intensity will help to better characterize the effect of sudden stratification in fluorescence quantum yield, changes in daily light patterns will attempt to characterize the effect of different mixing rates.

The study of the effect of temperature in fluorescence quantum yield will first be limited to document the minimum change in temperature required to observe a change in phytoplankton fluorescence. Previous studies have noted the existence of an inverse relation between temperature and fluorescence quantum yield when comparing measurements collected in pelagic ecosystems ranging from the Sargasso sea to the Antarctic Ocean. However, it is not clear if these observed changes where the direct effect of temperature in the distribution of energy in the photosystem, or if they were the result of comparing

different phytoplankton assemblages.

Although we will first keep our experimental protocols simple in order to evaluate the response of phytoplankton to changes in a single environmental variable, in time we plan to mimic changes resulting from variations in mixed-layer depth and nutrient upwelling. Furthermore, because there is an intrinsic coupling between nutrient availability and light utilization, nutrient limitation may have an important effect in the capacity of phytoplankton to photoadapt. For example, nitrogen limitation affects photosynthesis at both light and dark reaction levels. Deficiency in nitrogen may decrease the chlorophyll a and Rubisco concentration in cells. Hence, it will be important to evaluate how nutrient availability affects the rate of change of fluorescence quantum yield in response of changes in solar irradiance and temperature.

Finally, in order to be able to use laboratory results in the interpretation of scales of variability observed in natural assemblages, we will need to assess how significant are intra and interspecific differences in the fluorescence response. This issue will be addressed by performing repeated experiments in different species. Because our efforts will be directed toward better understanding the physical-biological coupling observed in the California Current System we will be working primarily with phytoplankton taxa representatives of this pelagic system.

A natural fluorescence chemostat has been modified to allow automated high temporal resolution (4 seconds) sampling of natural fluorescence (photomultiplier DC current), fluorescence yield (photomultiplier AC current per unit monochromator light), Photosynthetic Available Radiation (PAR), temperature, and pH. Other parameters sampled at high frequency will include photosynthetic parameters derived from Fast Repetition Rate Fluorometry (variable fluorescence and effective absorption cross section) as well as changes in the 400-700 nm spectral absorption of the culture.

Discrete samples will be collected at critical points (such as early morning, noon, and late evening) for cell counting and the analyses of absorption cross section, pigment and particulate elemental composition (C,N,P). Initially, macronutrient (nitrogen and phosphorus) will also be analyzed from discrete samples. In a later phase we will plan on having nutrients being continuously measured by installing on line an autoanalyzer. The analyses of these samples will allow us to better understand the different scales of adaptation taking place at the photosynthetic and cellular structural level and contributing to the change in fluorescence yield.

EOSDIS Plans

We have continued our work on distributed objects frameworks for EOS data retrieval and analysis. This work was supported through a contract with the Raytheon ECS prototyping activity. A final report may be found at http://picasso.oce.orst.edu/users/mark .

Along with the MODIS Web documentation, we are revising our archive of satellite and in situ data sets. With the release of SeaWiFS data, we are now assembling a data base of both SST and chlorophyll for the Southern Ocean region. This will also include our bio-optical drifter and mooring data.

Anticipated Future Actions

- Retrieve and redeploy bio-optical mooring in Hawaii and continue analysis of bio-optical data
- Analyze data from bio-optical moorings and drifters, TSRB II, and FRR in the Antarctic Polar Frontal Zone
- Continue chemostat experiments on the relationship of fluorescence quantum yield to environmental factors. Establish relationship between fluorescence quantum yield and photosynthetic parameters.
- Continue to develop and expand browser-based information system for in situ bio-optical data.

Problems and Solutions

The most significant concern remains the apparent inability of EOSDIS to deliver data products at launch. We are concerned that insufficient data will be delivered for algorithm validation as well as analysis in support of future EOS sensor designs. In particular, much of the quality assurance will depend on delivery of data over the network; there is little leadership within ESDIS on network design. With the continuing

delays of the AM-1 launch and the push to PI processing, the network will increase in importance. Unless a coherent strategy is designed and implemented, it will be unlikely that we will meet our data delivery requirements.